

Structural Value Of *Empyak*

A. Robbi Maghzaya¹, Prihatmaji, Yulianto², Pradipto, Eugenius³

¹Architecture, Universitas Islam Indonesia, Jl. Kaliurang Km 14.5 Sleman Yogyakarta

²Architecture, Universitas Islam Indonesia, Jl. Kaliurang Km 14.5 Sleman Yogyakarta

³Architecture, Universitas Gajah Mada, Jl. Grafika 2 Sleman Yogyakarta

arobbimaza@gmail.com, prihatmaji@uii.ac.id, epradipto@yahoo.com

ABSTRACT

Empyak is a part of the traditional building that must be developed to preserve its existence. This paper explores the impact of construction method and structural behavior of *empyak*. The identification of how structurally work is essential as a primary information to develop the construction of *empyak*. Initially, a model with scale 1:3 was made to understand structural behavior under the seismic simulation. Some observation will be done to find out the changing of its shape under seismic forces. The results of this research are limited to understand the function of every element in the building stability. The result of the study will be useful for the development of traditional architecture. *Empyak* not only regards as a construction element but also as a structural element, which is the subject of the study.

Keywords: *Empyak, structure, construction, bamboo*

ABSTRAK

Empyak adalah salah satu elemen bangunan tradisional Yogyakarta yang perlu dilestarikan. Artikel ini membahas mengenai konstruksi *empyak* terhadap perilaku struktur bangunan keseluruhannya. Bagaimana *empyak* bekerja sebagai elemen struktural perlu dipelajari untuk dikembangkan dengan metode yang lebih modern. Pemahaman mengenai perilaku struktur *empyak* dilakukan dengan pengamatan model konstruksi dibawah berbagai karakter pembebanan. Observasi terhadap model berfungsi untuk mengetahui perubahan bentuk setelah dilakukan pembebanan. Penelitian ini dibatasi pada fungsi-fungsi struktural setiap elemen *empyak* untuk mendapatkan bangunan yang stabil. Penelitian ini bermanfaat untuk memahami bagaimana nilai-nilai konstruksi dan struktur yang ada dalam konstruksi *empyak*.

Keywords : *Empyak, struktur, konstruksi, bambu*

INTRODUCTION

In south-east Asia, there is many culture variety. Its always become attractive and have a high impression to the visitor or tourism (Waterson, 1998). In term of architecture, we can identify the uniqueness of its construction by the shape of the roof. For example, in Indonesia, almost every province has distinguished form of the roof. *Gadang*, *Karo*, *Nias*, *Panjang*, *Tongkonan*, and *Honai* are the example of houses that have distinctive shape of the roof.

Java island in Indonesia also has a traditional building with a unique shape that reflects the richness of Javanese culture. Traditional architecture in Java, especially in Yogyakarta, like *Panggung Pe*, *Joglo*, *Limasan*, *Kampung*,

and *Tajug* are distinguished by the shape of the roof (Ismunandar, 2007). Another variation in traditional roof construction is *empyak*.

Empyak is one of the roof elements in the traditional building construction. Construction *empyak* mostly is used by people from mid-low social level. The usage of *Empyak* primarily constructed in two type of the roof, which is *kampung* and *limasan* houses (see Figure 1).

Empyak, geometrically, has a various kind of shape. It depends on the type of the roof. *Kampung* house uses the combination of two rectangular *empyak*. While in the *limasan*

building, we can find the combination of trapezoid and triangle shape (see Figure 2). There are several types of bamboo arrangement in *empyak* construction. *Empyak* was a cheap solution that can be reached by mid-low range people to get a house that structurally qualified.

This element is constructed on the ground before attached to the top of the structure. After the panel completed, the worker will lift it manually on the top of the structure frame. So, every part of an *empyak* element not assembled piece by piece directly on the top of the structure, like conventional way.

The roof is an essential element of the building, so that, its design will be unique (Soeroto, 2003), especially for traditional building in a tropical area like south-east Asia. This uniqueness can be the identity of culture in some place. But, now, there is a challenge in present day to use the old construction methods. The demand of modern culture needs the more efficient way and system which is difficult to achieve by traditional systems. This problem also occurs in the use

of traditional construction, such as *empyak*. Modern people will tend to use new technique or material that much easier to be applied than old construction. In case of *Empyak*, this shift causing *this technology* not develop, and gradually abandoned.

Empyak lies on the structure of the building that generally, have similar construction and element. The main structure of Yogyakarta traditional wooden traditional called *rong-rongan* (Frick, 1997). *Rong-rongan* is frame system that consists of *sokoguru*, *blandar*, *pengeret*. In comparison, there is no triangle truss element as a primary roof support like in *conventional* roof structure. So the question is how *empyak* construction can afford its stability from the lateral force?, while its main structure not stable under low-frequency seismic force (Prihatmaji, 2007).

This paper seeks to explore the construction method and structural behavior of *empyak* to reach building stability. An understanding of both construction and structural aspect can be used to develop the origin technology of the building in Indonesia.



(a)



(b)

Figure 1. *Empyak* construction of *limasan* roof (a) and *kampung* roof (b)
(Source: author)

METHODOLOGY

First of all, to understand how the empyak works structurally and constructionally, *empyakit* needs to identify the original construction. Start with the study of two sample from two different types of traditional houses in Yogyakarta that is *kampung* house and *limasan* house. That use empyak for its *roofing* element. These two buildings represent typologies of *empyak* basic form.

Some interview with traditional craftsman of *empyak* has been done to know the detail of the construction process. After collecting interview and observation data, this research will build a model of empyak in scale 1:3 as a tool for the simulation to study the structural behavior.

This research will observe on the construction stability before its attached to the main structure and observe the structural stability after *empyak* panel attached to the main structure. The experimental treatment has been done manually to apply tension force, compression force, bending force, torsion force (Cowan, 1971) and shear force (Ravi Malapundi and Ayoub, 2010) on the construction. Every treatment on the model will be observed the changes of its shape and identify the elements that react to the forces.

BASIC THEORY

The structure must fulfill the requirements of stability in every possible loading condition (Schodek, 1995). So that, to determine whether it has structural value or not, it can be seen from the symptom of the stability of the construction by transmission of the force from one spot to another (Marshall, 1969). As structural element *empyak* also need to maintain not only the stability of the panel itself but also the stability of the whole systems that work on the building.

Empyak is plane elements of the roof made from bamboo tied into one panel. *Empyak* composed by several elements, namely *gendong*, *gapit*, *usuk*, *reng*, and *gapit kupu tarung* (Hamzuri). Every element tied together with a traditional rope called *ijuk*. *Ijuk* is made from the part of aren tree (*Arenga pinnata*). Initially, *empyak* do not use nails to strengthen the joint. Javanese peoples belief nails are not strong enough to hold all the

connections and can damage the material (Frick, 1997).

The important aspect that determines the structure whether strong or weak is construction joints. The joint properties and condition will influence the structure system of the building. The weaker joint can makes the system of the structure fail (Cowan, 1971). The top connections between empyak and the frame of the building use bonding system with a traditional rope called *plilit* made from bamboo. While in the bottom support is locked with wooden pegs. Pegs and rope serve as an anchor to prevent *empyak* panel apart from the main structure and lifted by the wind (Crane, 1947).

The wind force on the roof must be considered to achieve stability of the building. Yogyakarta traditional buildings have a relatively tall shape of the roof that will create greater wind force on the roof compared to building with flat roof.

Empyak construction uses bamboo as a material alternative for wood as the main structure of the traditional building in Yogyakarta. Bamboo is more economically feasible material (Ghavami, 2008). It easy to plant, harvest, and treatment. The other advantages of bamboo are easy to construct, resilient to the wind force, resilient to earthquake forces, and easy to repair in the event of damage (Jayanetti, D.L. & Follett, P.R., 2008).

Traditional roof construction needs into two types, namely stilts roof system and truss system construction (Frick, 2004). Among the two types of roof construction, the truss system is more stable to withstand lateral forces because it has a diagonal formation (Schodek, 1997). While on the stilts roof system, there are elements called *ander* that need to be combined with other elements as stiffeners. *Ander* is a vertical beam that sustains molo, mounted perpendicular to the *pengeret* beam. *Ander* is only founded in the *kampung* and *limasan* houses (Ismunandar, 2007).

RESULT AND DISCUSSION

1. Construction of *Empyak*

Empyak is the composition of bamboo materials combined with *ijuk* rope. *Empyak* usually can be found in two types of Yogyakarta traditional houses, which are *kampung* and *limasan*. All of the *empyak* components are made from a different cut of bamboos.

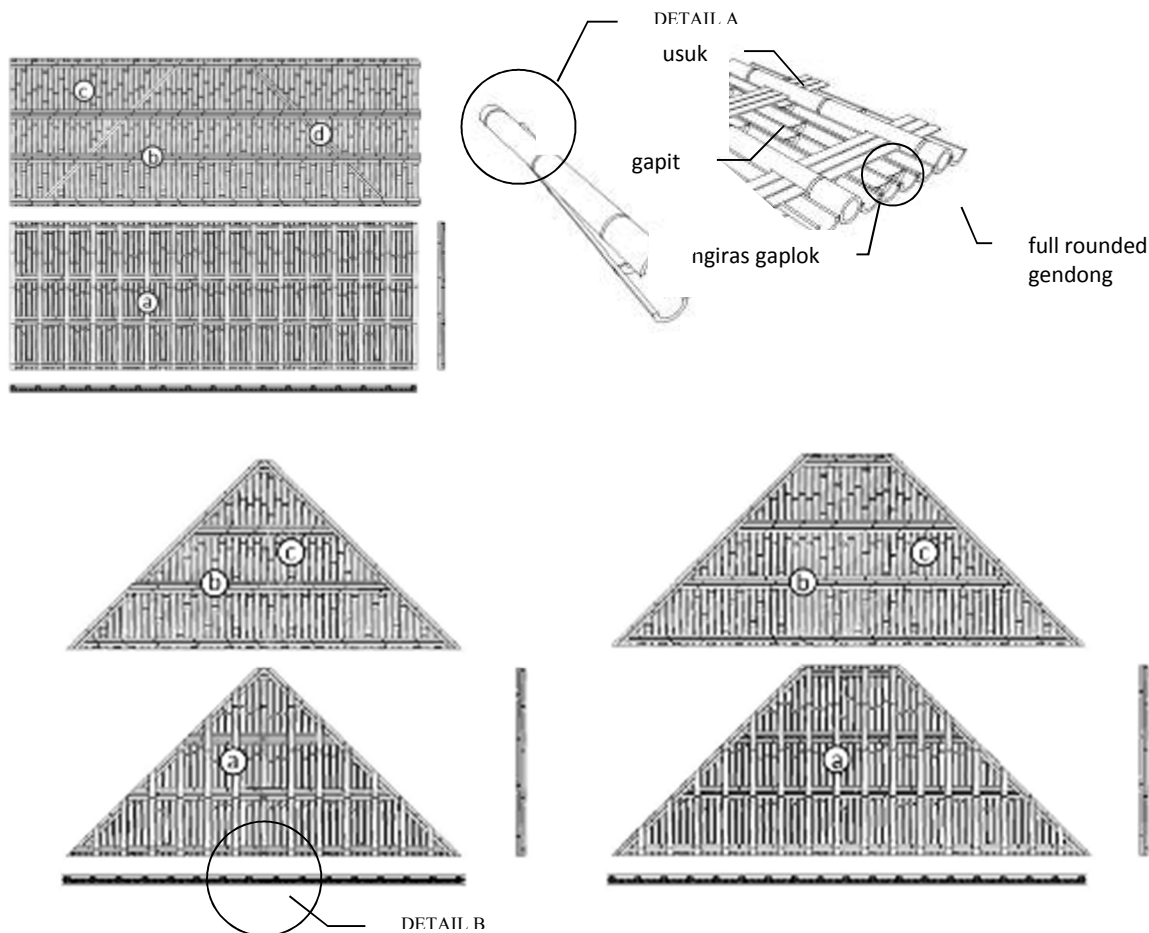
Gendong is made from full round or half round cross section bamboo placed in every 3-4 of *usuk*. Full shape *gendong* has several holes, called *ngiras gaplok* across the rod to allow *gapit* insert *gendong*. The placement of *gendong* always puts the bottom of the rod on the peak of the roof. This because the bottom side of the bamboo is more resistant to water and moisture than the opposite side.

Gapit serves to unite *usuk* of *empyak* by flanking. Every panel consists of a pair of 2-3

rod of split bamboo. *Gapit* on the back side of *empyak* placed through *the gendong* hole to obtain uniform clamping on the surface of *usuk*, as well as preventing *the gapit* slide down when vibration occurs in *empyak*.

Usuk is made from bamboo that split into two. So, it has half circle cross-section, and it is arranged parallel with *gendong* and perpendicular with *gapit*.

Gapit sidang or *gapit kupu tarung* are diagonal elements to maintain the stability of the rectangular *empyak* panel. These features only are found in rectangular *empyak*. Unlike *gapit*, *gapit sidang* is constructed not in a pair but only on the front side of the *empyak* and tied with *usuk*.



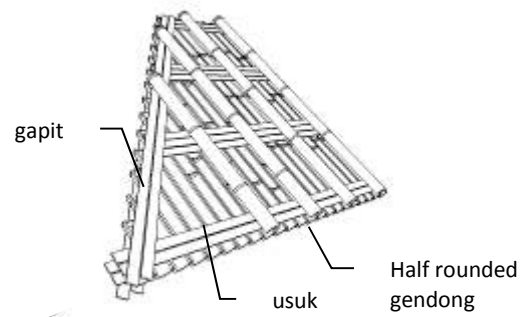


Figure 2. *Empyak* Panel Assemblies: *Gendong* (a), *Gapit* (b), *Usuk* (c), *Gapit Sidang* (d). (Source: author)

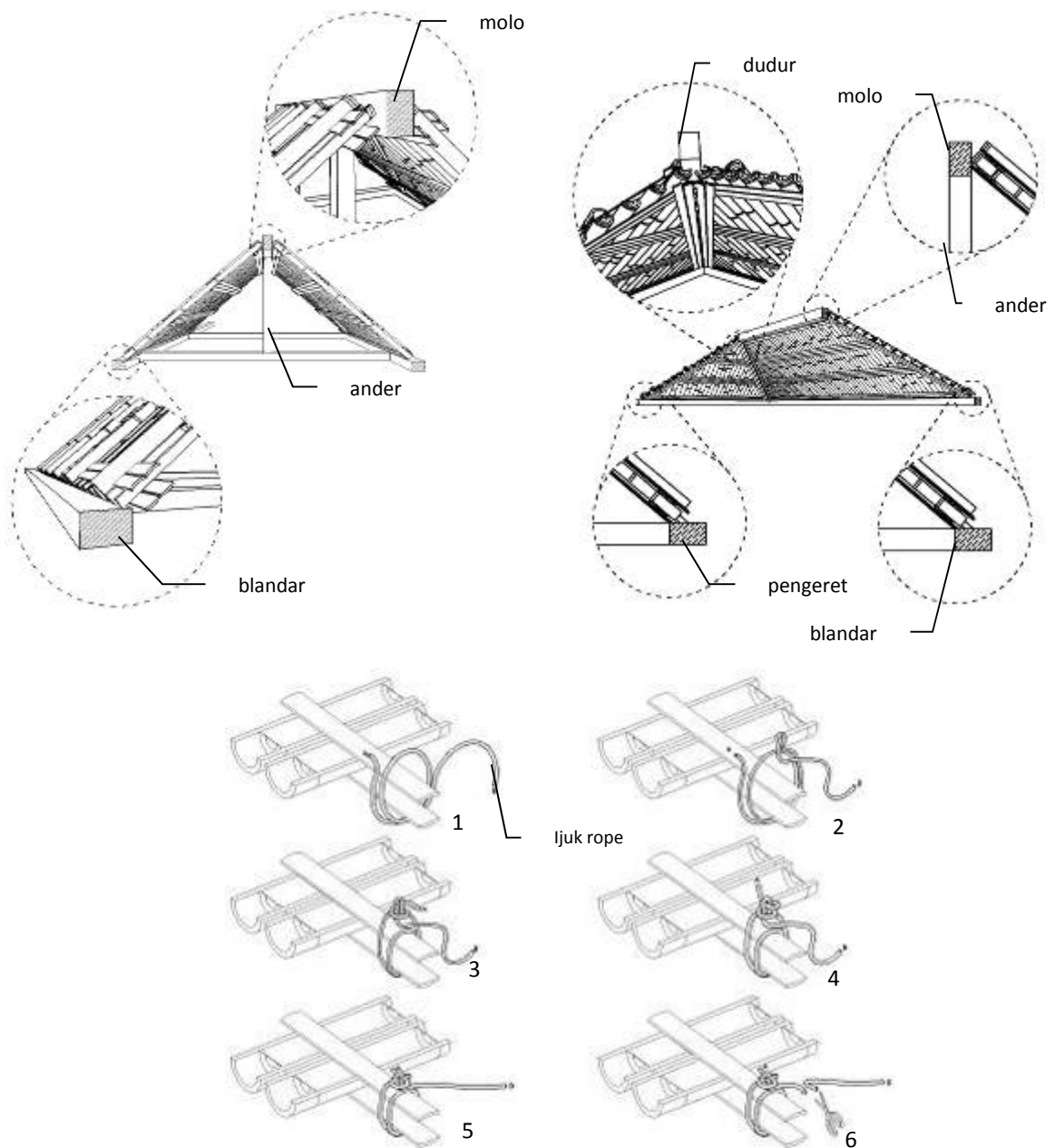


Figure 3. *Empyak* Assemblies Detail (Source: author)

Each component is arranged with a tied system using traditional rope called *duk* or *ijuk*. This material is reliable and very simple to be applied. The principal of *ijuk* knot is by pulling a pair of *gapit*, so that will clamp *usuk* from both sides because the bamboo is an elastic material. It can return to its original shape when stress is removed (Schodek, 1998). So, when two opposing *gapit* tied up, it will react to tighten the clamps. There is a specific looping technique to use *ijuk* rope. The benefit of this method is it safer to tied it up a bare hand. *Ijuk* had a sharp tip and stiff properties that can hurt human skin.

All of the *empyak* panels must be placed on the structure frame (*rong-rongan*). In *kampong* houses, the *empyak* panel must rely on *blandar* beam (cc1). In *limasan* type, trapezoidal panel relies on *blandar*, and triangle panel will rely on *pengeret* beam. At the roof peak, all panel rely on *molo* beam. At the bottom connection, the panel was detained with wooden anchors, so that the panel will not slip down. At the upper connection, the panel was tied to *molo* with the bamboo rope called *plilit*. The diagonal side of the panels (*limasan* house) will be hung on the serving beam.

On the tip of the roof, there is the additional element which is the extension of the *gendong*, which to support ridge cover at the top of the roof. The upper rod tip of this element will meet each other from the opposite panel.

2. *Empyak* as a Part of The Structure System

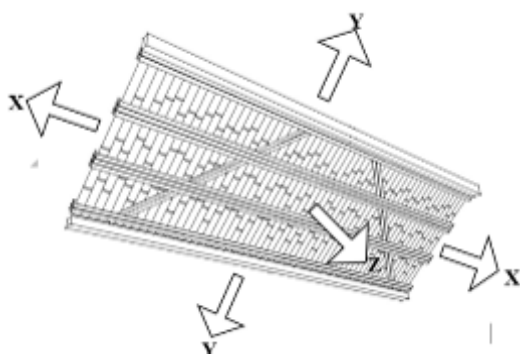


Figure 3. Force Direction Analysis (Source: author)

The element of the building would be structural value if it became a part of loading transmission system of the building. One parameter of structure is the stability of the shape. Several forces can affect the stability of the building. This paper will examine the effect of tension force, compression force, bending force, shear force, and torsion force to the *empyak* construction. The force that possibly works on *empyak* construction from x-axis, y-axis, z-axis directions needs to be examined to understand the effect of force on construction stability.

2.1. Compression Force Analysis

When compression force occur to an object, it will tend to shorten (Schierle, 2006). Compression force that works in the direction of y-axis is detained by *usuk*. The close arrangement of *usuk* will keep the stability of *empyak*. The installation angle of *empyak* can potentially cause *empyak* pushed out from the *blandar* beam. There is some wooden anchor to lock the downside of the panel and detain the movement.

The compression force of x-axis direction is perpendicular with *usuk* rods. Half-circle *usuk* unstable to withstand the force from the side. There is two possibility that happens to the material of *usuk*. First, the *usuk* will be distorted because of pressure. In this case, the tightness of *gapit* clamps will help *usuk* still on its position. Second, if the compression force is strong enough, it could crack the material of *usuk*. So the knots of bamboo play its part to strengthen the bamboo material from cracking.

The compression force that perpendicular to the *empyak* surface (z-axis) do not affect the stability of *empyak* significantly. It is because there is loads from above but no counter loads from below. So the compression forces will not work in this direction.

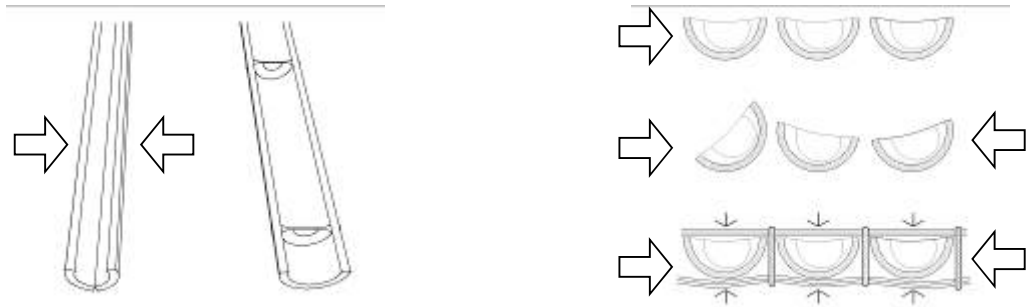


Figure 4. *Usuk* Construction Failure (Source: author)

2.2. Tension Force Analysis

When tension force occurs to an object, it tends to elongate (Schierle, 2006). The *empyak* ability to resist the tension force of x-axis direction is fragile because all the connection of each element only use rope. *Empyak* is not a homogeneous panel. If *empyak* pulled from the x-axis, the arrangement of *usuk* could be stretchable. In reality, this potential treatment happens when the transporting or installation process.

In the y-axis direction, the tension force tends to disrupt the arrangement of *empyak* to the tension strength of bamboo quite high (Widyowijatnoko, 2008), it does not affect the stability of the panel. It because the panel construction makes every rod to withstand tensile force individually. In reality, the level of tension from these direction almost zero when it already installed on the primary structure.

The tension force that perpendicular with the surface of *empyak* (z-axis) do not affect the stability of *empyak* significantly because there is tension on the surface of the *empyak*. So the tension forces do not work in this direction.

2.3. Bending Force Analysis

When bending force occurs to an object, it will tend to elongate on one side and shortens on the other side (Schierle, 2006). On the y-axis direction, it is difficult to bend the panel because of the width of the panel. The higher the vertical cross-section of the beam, the greater the ability to withstand bending forces. (Baden-Powell, 2001).

Other than that, if we try to put force on the y-axis of the panel and parallel to the

direction of *usuk*, it will slide the *usuk* from the original position. The installation of *empyak* must prevent the movement of *usuk* by putting the downside of the *empyak* panel on the top side of *blandar* or *pengeret*. So that, every *usuk* will step on the plane surface of the beam.

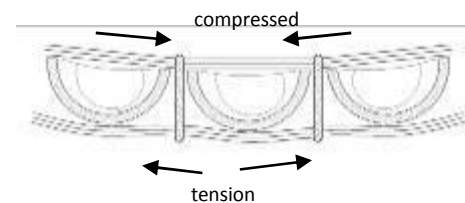


Figure 5. Effect of Bending Force to *Empyak* (Source: author)

As an individual material, the force from the side will bends *usuk*, but as a panel it hard to bend the panel in the x-axis direction. The essential elements to resist bending force front x-axis are the *usuk* and the strength of the tie. The tight assembling of *usuk* could reduce *usuk* to buckle. The other element is *gendong*. With circular cross-section, *gendong* is stronger to resist bending forces compared to half-circular cross section *usuk*.

There are two-ways of bending force on this Z-axis direction, transverse and longitudinal to the direction of *usuk*. Elements that play its part to resist transversal buckling is *usuk* and *gendong*. Elements that play its part to resist longitudinal buckling is *gapit*. *Gapit* at the front side and the back side of *empyak* will work together to resist buckling. When the front *gapit* withheld tension force, the backside *gapit* will withhold compression forces. And the other hand, when the backside *gapit* withstand tension force, the frontside *gapit* will withstand compression forces.

2.4. Shear Force Analysis

When shear force occurs to an object, it will slide the adjacent part of the element (Schierle, 2006). The arrangement of *usuk* without rigid locking systems will be very easy to slide. The effect of sliding only reduced by the tightness of the *ijuk*. When the force from the direction of x-axis and y-axis occur, the tie system will take part to stabilize the construction. The stronger the tie, the

stronger the friction between *usuk* and *gapit*. The other elements that will help the panel to resist shear force are *gapit sidang*. *Gapit sidang* serves as the diagonal system to obtain stable forms (Schodek, 1995).

The effect of shear force on the direction of z-axis barely not seen because of the thick of panel is too small compared to the length and the width of *empyak* so that it will reduce moment force.

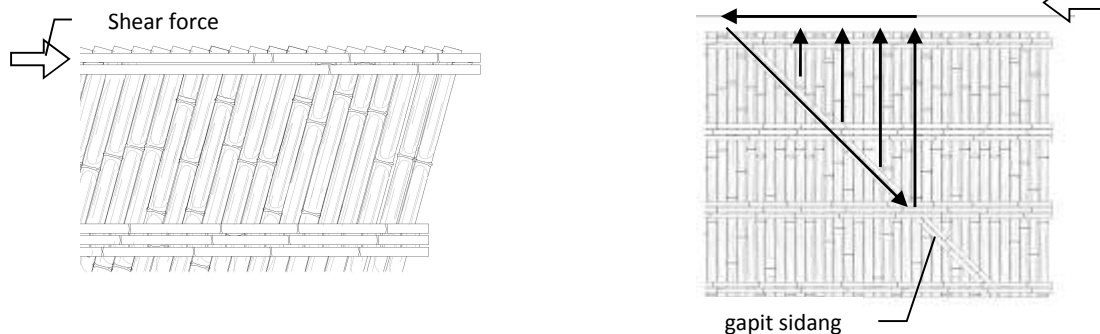


Figure 6. Effect of Shear Force to *Empyak* (left) and Resistant Mechanism to Shear Force (right) (Source: author)

2.5. Torsion Force Analysis

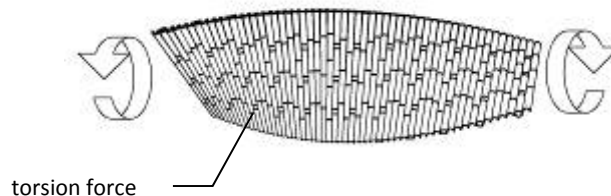


Figure 7. The Effect of Torsion Force to *Empyak* (Source: author)

The torsion force will twist the panel (Schierle, 2006). *Gapit* and *gapit sidang* both resist the torsion force from the x-axis and the y-axis direction. The construction of *empyak* so prone to maintain its stability form torsion forces. The thickness of the *empyak* panel is too small compared to its length and width. So it makes *empyak* very easy to twist with small effort. So, traditionally, to lift up the *empyak* panel, many people needed, not just because of the weight, but the more people will maintain the stability of its shape during the lifting process. After it is placed in the main structure, the stability of the panel will depend on the structure stability.

2.6. Joint

Empyak is not united with stiffed joints to the main structure. The bottom connection is composed of a wooden peg that is inserted into the hole part of the bamboo. The upper connection is tied with the bamboo rope (*plilit*). Both kinds of the connections give the advantages to reduce the vibration energy, like the earth quake. Because, the stiffed joint will transmit the tremor to other building elements (Maer, 2008).

According to the explanation above, we can identify the function of each elements to resist external forces from many directions, and maintain the stability of the structure, as in the table below.

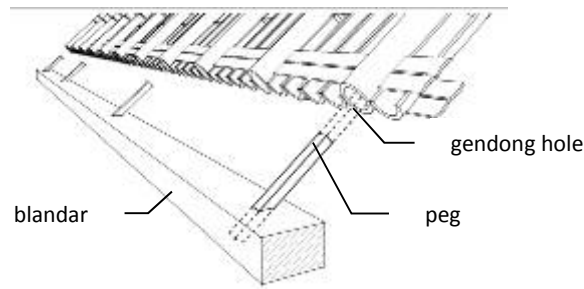


Figure 8. Detail of Bottom Connection of *Empyak* (Source: author)

CONCLUSION

Tabel 1. The Role of *Empyak* Elements to Resistant Forces

FORCES		USUK	GENDONG	GAPIT	GAPIT SIDANG	NOKI MOLO	BLANDAR	IJUK	SUMMARY	TOTAL
COMPRESSION	X-axis	√	√	√	-	-	-	-	3	8
	Y-axis	√	√	-	-	√	√	-	4	
	Z-axis	-	√	-	-	-	-	-	1	
TENSION	X-axis	-	-	√	-	-	-	-	1	5
	Y-axis	√	√	-	-	√	-	-	3	
	Z-axis	-	-	-	-	-	-	√	1	
BENDING	X-axis	√	√	√	√	-	-	√	5	15
	Y-axis	-	√	-	√	√	√	√	5	
	Z-axis	-	√	√	-	√	√	√	5	
SHEAR	X-axis	-	√	√	√	-	-	√	4	14
	Y-axis	√	√	√	√	√	√	√	7	
	Z-axis	-	√	-	√	-	-	√	3	
TORSION	X-axis	-	-	√	-	√	√	√	4	9
	Y-axis	√	-	√	-	√	√	√	5	
	Z-axis	-	-	-	-	-	-	-	0	
TOTAL		6	10	8	5	7	6	9		

(Source: author)

The *empyak* structure has diagonal elements (*gapit sidang*) which serves to maintain the stability of the shape from the influence of lateral forces. *Empyak* also serves to maintain the stability of the roof frame from both transverse and longitudinal directional force. Although the main frame of the building does not have diagonal bracing, such as truss, the *empyak* can replace the function of bracing to achieve structure stability. Most influential forces to *empyak* stability are bending and shear force. In the other hand, the least influential force to *empyak* stability is tension force. Elements that were most responsible for maintaining the stability of *empyak* are *gendong*, *gapit*,

and *ijuk*. The joint between *empyak* and the main frame is not a permanent and rigid so that it can serve as a vibration damper.

ACKNOWLEDGMENT

The authors would like to thank the Ministry of Research, Technology and Higher Education through grant scheme of the Overseas Joint Collaboration Research and International Publication (663/M/KP/XII/2015 and 041/HB-LT/IV/2017) to support this research.

This research was supported by Drs. M. Syakir Ali, M.Si. We thank our colleagues

from Universitas Islam Indonesia and Universitas Gajah Mada who provided insight and expertise that greatly assisted the research, although they may not agree with all of the interpretations/conclusions of this paper.

We thank Dr. Ir. Arya Ronald for assistance with writing technique, and for comments that greatly improved the manuscript.

We would also like to show our gratitude to the Universitas Gajah Mada for sharing their pearls of wisdom with us during this research, and we thank 3 "anonymous" reviewers for their so-called insights. We are also immensely grateful to Aspin Latif, ST., M.Sc., Irwan Dharmawan, ST. M.Sc for their comments on an earlier version of the manuscript. Although any errors are our own and should not tarnish the reputations of these esteemed persons.

REFERENCES

- Baden-Powell, Charlotte. (2001). *Architect's pocketbook/Charlotte Baden-Powell – [2nd ed.]*. p. cm. Includes index ISBN 0 7506 4764 7. Burlington: Elsevier
- Cowan, Henry J. (1971). *Architectural Structures: An Introduction to Structural Mechanics*. American Elsevier: Newyork.
- Crane, Theodore. (1947). *Architectural Construction*. John Wiley & Sons: New York.
- Frick, Heinz. (1997). *Pola Struktural dan Teknik Bangunan di Indonesia*. Kanisius: Yogyakarta
- Frick, Heinz. (2004). *Ilmu Konstruksi Bangunan Kayu*. Kanisius: Yogyakarta
- Ghavami, K. (2008). *Bamboo: Low cost and energy saving construction materials*. *Modern Bamboo Structures – Xiao et al.* (eds) © 2008 Taylor & Francis Group, London, ISBN 978-0-415-47597-6
- Hamzuri. *Rumah Tradisional Jawa. Proyek Pengembangan Permuseuman DKI Jakarta. Seri Rumah*. Departemen Pendidikan dan Kebudayaan.
- Ismunandar. (2007). *Joglo : Arsitektur Rumah Tradisional Jawa*. Effhar: Semarang
- Jayanetti, D.L. & Follett, P.R. (2008). 23 *Bamboo in construction*. *Modern Bamboo Structures – Xiao et al.* (eds) © 2008 Taylor & Francis Group, London, ISBN 978-0-415-47597-6
- Maer, Bisatya W. (2008). *Respon Pendopo Joglo Yogyakarta Terhadap Getaran Gempa Bumi*. DIMENSI TEKNIK ARSITEKTUR Vol. 36, No. 1, Juli 2008: 1 - 9
- Marshall, W. T. (1969). *Structures*. London: Pitman
- Prihatmaji, Yulianto P. (2007). *Perilaku Rumah Tradisional Jawa "joglo" Terhadap Gempa*. DIMENSI TEKNIK ARSITEKTUR Vol. 35, No. 1, Juli 2007: 1 – 12
- Ravi Mullapudi, T., Ayoub, Ashraf. (2010). *Modeling of The Seismic Behavior of Shear-critical Reinforced Concrete Columns*. Journal Engineering Structures Vol. 32, Issue 11, Pages : 3601-3615
- Schodek, Daniel L. (1997). *Structure*. Bandung: Refika Aditama.
- Schierle, G.G. (2006). *Architectural Structure Excerpts*. Los Angeles: University of Southern California.
- Soeroto, Myrtha. (2003). *Dari Arsitektur Tradisional Menuju Arsitektur Indonesia*. Galia Indonesia: Jakarta
- Waterson, Roxana. (1998). *The Architecture of South –East Asia through Travelers' Eyes*. Oxford University Press: New York.
- Widyowijatnoko, A. *Prefabricated low-cost housing using bamboo reinforcement and appropriate technology*. *Modern Bamboo Structures – Xiao et al.* (eds) © 2008 Taylor & Francis Group, London, ISBN 978-0-415-47597-6